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RESEARCH ARTICLE

Survival and growth of Common beech (*Fagus sylvatica* L.) provenances in North-Eastern Bulgaria

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Abstract

Two provenance tests in North-Eastern Bulgaria have been studied, whose purpose is to test the response of beech provenances from Southern Germany to the drier and warmer climatic conditions in Bulgaria, in order to predict how they would perform in a warming and drying climate. The provenance tests were established in the spring of 2010 in the area of the Varbitza and Kipilovo Forest Services with 2-year-old seedlings in a 2 x 1 m scheme in 3 replications. Four provenances of common beech were studied - 2 German (Silberbach and Ebersdorf) and 2 Bulgarian (Petrohan and Berkovitza). On the 12th year after afforestation, an inventory and measurements of the height and root collar diameter were carried out. The results were processed statistically by applying one and two-factor analysis of variance, as well as Tukey's test for multiple comparisons. A higher survival rate was found in the provenance test in Kipilovo. The Bulgarian provenances Petrohan and Berkovitza were characterized by better growth in height in both provenance tests, and in root collar diameter - provenance Petrohan. Provenance Ebersdorf could be recommended for use in drier and warmer places in Southern Germany.

Keywords

Fagus sylvatica, seedlings, survival rate, height, root collar diameter, provenance test

Introduction

Common beech (*Fagus sylvatica* L.) is a widespread broad-leaved tree species with great economic and ecological importance. In Europe, it occupies an area of about

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14 million hectares (von Wüehlisch 2010 according to Ballian and Zukić, 2011), and in Bulgaria it represents 16.5% of the total forested area of the country. It is attached to fresh and moist, medium rich to rich habitats and high air humidity. Because of these ecological features, common beech is threatened by projected climate changes. Its adaptability to changing climatic conditions is the subject of studies in provenance tests, in which the ecological plasticity of different provenances is assessed under changed climatic conditions in place of the provenance test. The first common beech provenance test in Europe was established in 1877 in a botanical garden in Germany (Kienitz 1886 - according to Ballian and Zukić, 2011), but it was not scientifically analyzed. In a common beech provenance test, established by Engler in 1908, it was found that beech provenances from northern areas and higher altitudes grew more slowly than those from lower and southern locations (Burger (1933, 1948) according to Višnjić and Dohrenbusch 2004). A staked experiment with 45 common beech populations in 6 provenance trials in Poland found that provenances from places where common beech is not widespread were characterized by relatively low survival and slow growth rate (Barzdajn, 2002).

Studies of common beech provenances in Slovakia have focused on growth in height and diameter and their seasonal dynamics, as well as spring phenology (Paule, 1982). In the spring of 1998, a provenance test with 38 common beech provenances from 15 European countries was established in Slovenia. At the 10-year age of the seedlings, the highest survival rate was found in the Belgian provenance Soignes – 94%, and the tallest plants – in the local Slovenian provenance (Postojna – Masun) – 242.8 cm. Some provenances Bretagne (France), Urach (Germany), Westfield (UK) were characterized by good adaptability and phenotypic stability, while others were phenotypically unstable (Nizbor and Horni Plana from the Czech Republic) (Ivanković et al., 2008).

In 2007, in Bosnia and Herzegovina, a provenance test with 22 common beech provenances (eight local, four from Germany, three from Serbia, two each from Croatia, Romania and Switzerland and one from Hungary) was established. In the third and thirteenth years after afforestation survival, height growth and root collar diameter were analyzed as well. The fastest and slowest growing provenances, and at the end of the 13th year, the tree shape were determined in order to evaluate their quality. Pearson's coefficient showed that height, root collar diameter, and tree shape are highly correlated. (Ballian, Zukić, 2011; Memišević Hodžić, Ballian, 2021).

The first common beech provenance test in Bulgaria was established in 1974 with provenances from the Training and Experimental Forest Range Petrohan, Etropole Forest Service and "Boatin" reserve and 7 variants of densities (Botev, 1988). There was a tendency to increase seedlings height at higher planting density. It was found that the density affects height growth more than the root collar diameter. From the tested three provenances with the highest growth indicators and as the most promising for the conditions of the Etropole-Lopian section of the Balkan Mountain, the provenance from the Training and Experimental Forest Range Petrohan was outlined (Botev, 1995).

A common beech provenance test from the international network of provenance tests in Europe was established in Bulgaria in the spring of 1994 on the territory of the Tvarditsa Forest Service at an altitude of 1160 m (Alexandrov et al., 2006). It includes 49 provenances, of which 33 from Germany, 5 from Slovakia, 2 each from the Czech Republic, Denmark and France and 1 each from Bulgaria, Estonia, Italy, Poland and Romania. In the first and fifth year after the establishment, a relatively high average percentage of survival is reported - 96.3 and 76.5%, respectively. The following years massive damage from wild animals was observed and the overall 12-year survival rate of the provenances test dropped to just 24.7%. Based on the measurements of the heights and root collar diameters of the seedlings at 1-, 5- and 12-year of the provenance test, the German provenances Herrenberg, Zwiesel and Eisenach were outlined as the most promising for the conditions of the experiment, and the worst results were shown by the Danish provenance Grasten.

The projected increase in mean annual temperature and decrease in annual precipitation has prompted studies to test the possibility of adaptation of common beech provenances from Central Europe to the warmer and drier climate of South-Eastern Europe (Bulgaria) in order to establish how they would play out under projected climate warming and drying. Thus, at the suggestion of the Bavarian Institute for Forest Seeding and Planting in Teisendorf (Germany) at the end of 2009 and the beginning of 2010, provenance tests of common beech of German and Bulgarian provenances were established, the purpose of which was to test the reaction of beech provenances of Southern Germany to the drier and warmer climatic conditions in Bulgaria to determine whether their adaptive capacity would be sufficient to maintain their vitality and productivity without significant changes. Results on phenological traits, as well as survival and height growth, during the first 3 years after the establishment of the provenance tests have been published (Petkova et al., 2017; Petkova et al., 2019). Of interest is the question of the behaviour of provenances 9 years later.

The aim of the work is to analyze the survival and height and root collar diameter growth of 4 common beech provenances in two provenance tests in North-Eastern Bulgaria in the 12th year after the afforestation.

Materials and Methods

The object of the study were four common beech provenances – Silberbach and Ebersdorf from Germany and Berkovitza and Petrohan from Bulgaria, introduced in two provenance tests in North-Eastern Bulgaria - on the territory of the Varbitza and Kipilovo Forest Services. Data on the location of the provenances and the provenance tests are presented in Table. 1 and Table. 2. The provenance tests were established in the spring of 2010 with 2-year-old seedlings under a 2 x 1 m scheme. In general, three replications per provenance were planted, with 50 seedlings each. The afforestation was carried out in slits. During the first 3 years after the establishment of the provenance tests, observations of survival and measurements of seedling heights were carried out, the results of which have been published (Petkova et al., 2019).

Table 1. Data for common beech provenances

Country	Provenance		MAT, °C	MAP, mm	Longitude E	Latitude N	Altitude m a.s.l.
	name	region					
Germany	Silberbach (S)	Oberbayern	6.0	700	12.18	50.13	611
Germany	Ebersdorf (E)	Oberfranken	6.5	900	11.33	50.50	650
Bulgaria	Berkovitza (B)	North Bulgaria	10.4	825	23.09	43.21	850
Bulgaria	Petrohan (P)	North Bulgaria	10.4	1004	23.14	43.15	800

Note: MAT – mean annual temperature; MAP – mean annual precipitation

Table 2. Data for the common beech provenance tests

Site	Longitude E	Latitude N	Altitude m a.s.l.	Exposition	MAT*, °C	MAP*, mm	Soil type	Site index
Varbitza	26.62	42.98	350	NW	11	708	Grey luvisols	$CD_{2,3}$
Kipilovo	26.22	42.88	500	NO	12.4	811	Grey luvisols	$CD_{2,3}$

Note: 1. MAT – mean annual temperature; MAP – mean annual precipitation. 2. In Bulgaria, a system is used to evaluate the site index, consisting of soil richness (A – very poor, B – poor, C – medium rich, D – rich) and a digital index for soil moisture (0 – very dry, 1 – dry, 2 – slightly moist, 3 – moist, 4 – very moist) (Raykov et al., 2011). CD2,3 means medium rich to rich and slightly moist to moist soil.

A survival assessment and measurements of heights and root collar diameters were carried out in the autumn of the 12th year after afforestation (2021)Statistical analysis was conducted after testing the hypothesis of constancy of variance across groups. Constancy of variance was confirmed by Levene's test, allowing analysis of variance (ANOVA) to be applied. The influence of the factors provenance test and provenance on common beech height and root collar diameter, as well as the interaction between them, was verified by applying one- and two-factor analysis of variance. Comparison of differences between the provenances was done by Tukey's method (Molle, 2012).

The data were processed statistically with statistical and graphical functions using environment libraries in the programming language 'R' (Wickham, 2009; R Core Team, 2022).

Results and discussion

Survival

Survival in the autumn of 2021 was compared to that in 2017 (Petkova, 2019).
The average survival rate of the four provenances in the provenance test in Varbitza in the 12th year after afforestation (2021) was 56.8 %. With the lowest percentage of survival was provenance Silberbach - 42%, and the highest - provenance Ebersdorf - 72%. Compared to 2017, there was a drop in the average survival rate from 63.6% to 56.8%. The decrease is from 3% at the Petrohan provenance to 10% at the Silberbach

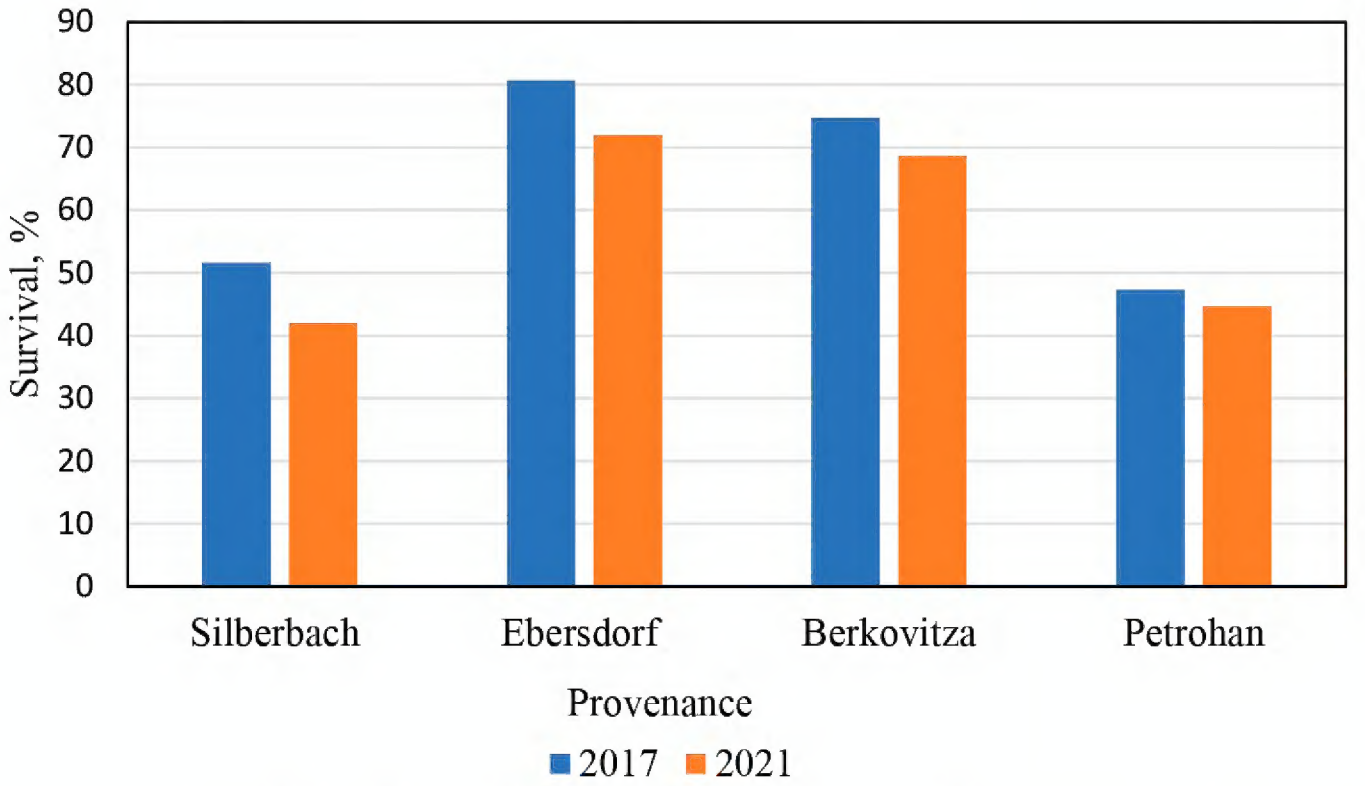

Fig. 1. Survival of the four provenances in Varbitza after the eighth (2017) and twelfth (2021) growth period

provenance (Fig. 1). The differences in the survival rates of the provenances were not statistically significant.

The average survival rate of the four provenances in the provenance test in Kipilovo in the 12th year after afforestation (2021) was 59% i.e. slightly higher than that in Varbitza (Fig. 2). The provenance Silberbach has the lowest survival rate - 48.7%, and the Bulgarian provenance Petrohan - the highest - 68%. It is noteworthy that the provenance Petrohan in this provenance test has significantly fewer losses compared to the same provenance in Varbitza. Compared to the eighth year (2017), here the average survival rate decreased minimally by less than 2%, evenly across the individual provenances, as in the provenance Petrohan, survival was only 0.7% less than in 2017. i.e. the survived individuals at year 8 persisted approximately at year 12. Here, too, the differences in survival rates were not statistically significant.

The higher average survival rate of the provenances in Kipilovo was probably due to the higher annual precipitation (811 mm) compared to Varbitza (700 mm), while in both provenance tests two cultivations were carried out in the first three years after afforestation. The ordering of provenances by survival rate was different in the two provenance tests. While in Varbitza the German provenance Ebersdorf was characterized by the highest survival rate, in Kipilovo the provenance Petrohan was the one with the least losses. From their studies of the provenance trials of 22 European common beech provenances in Bosnia and Herzegovina, Ballian and Zukić, (2011) found that local provenances had the highest survival rate and concluded that the local provenances had better adaptability. In a provenance test in Slovenia the best survival was observed in a Belgian provenance (Ivanković et al., 2008). There was no definite conclusion about better survival of local provenances and in studies in common beech provenance trials in Croatia and Serbia (Stojnić et al., 2015).

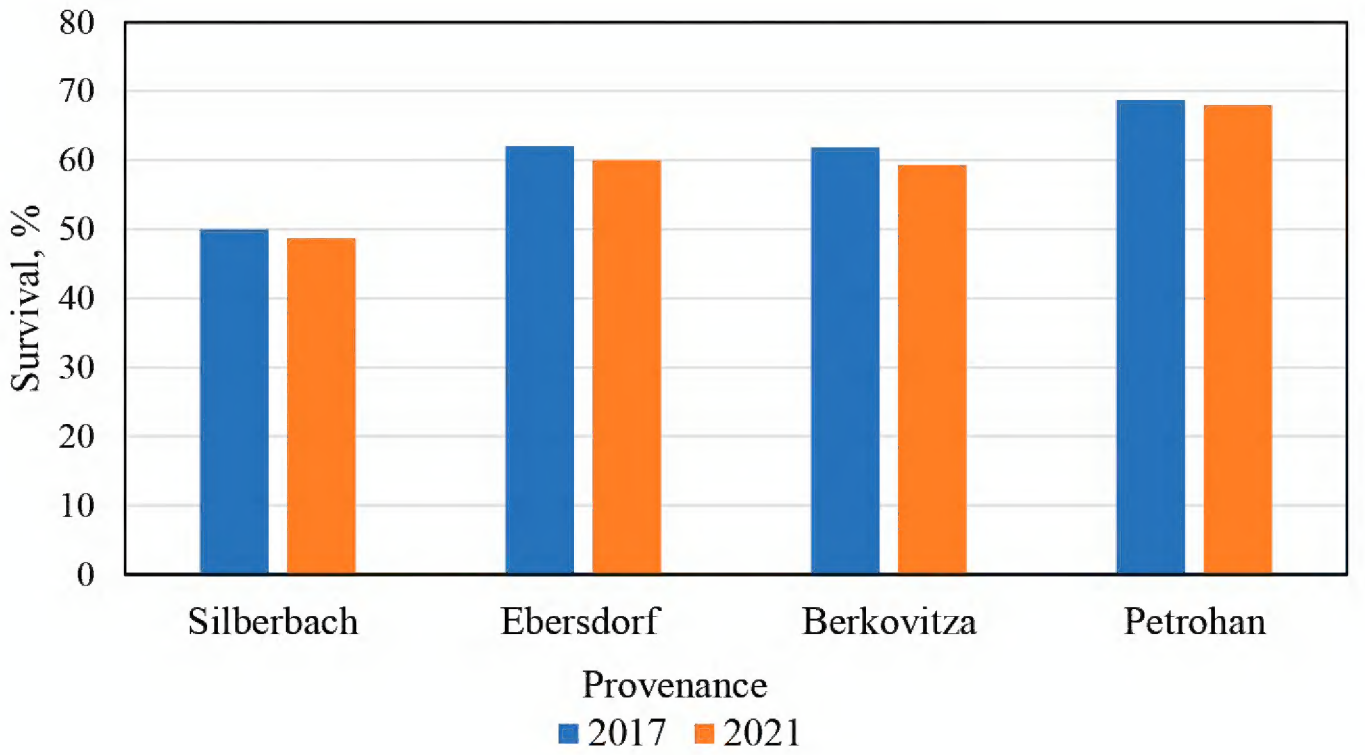

Fig. 2. Survival of the four provenances in Kipilovo after the eighth (2017) and twelfth (2021) growth period

Height growth

The influence of the factors provenance test (PT) and provenance on the height of the beech trees is presented in Figure 3. It could be seen that the provenances differ quite distinctly in height, and in both provenance tests the Bulgarian provenances were taller. The mean height of provenance Petrohan was the highest, followed by provenance Berkovitza. The German provenance Ebersdorf had roughly the same height in both provenance tests. The lowest in both tests was the provenance Silberbach. The mean height of the common beech in the provenance test in Kipilovo exceeds that in Varbitza, but the difference wasn't as obvious as in the provenances.

The result of the statistical test (two-factor analysis of variance, ANOVA) shows (Table 3) that the height of the common beech seedlings wasn't statistically significantly affected by the location of the provenance test (PT), but only by the provenance. There wasn't any statistically proven influence between the two factors – provenance test and provenance.

The mean heights of provenances in the two provenance tests were presented in Figure 4. The mean height of the provenances in Kipilovo was 311.5 cm and slightly higher than that in Varbitza (305.4 cm), as could be seen from Fig. 3 too. With the highest mean height in the 12th year after afforestation was the provenance Petrohan (349 cm in Kipilovo and 336 cm in Varbitza), followed by the provenance Berkovitza, and the smallest - the German provenance Silberbach (240 cm in Kipilovo and 260 cm in Varbitza). The high level of significance of provenances indicated in Tab. 3, allows Tukey's multiple comparison method to be applied.

From the comparison of the mean heights in pairs (Table 4), it was noticeable that the mean height of provenance Berkovitza does not differ statistically significantly

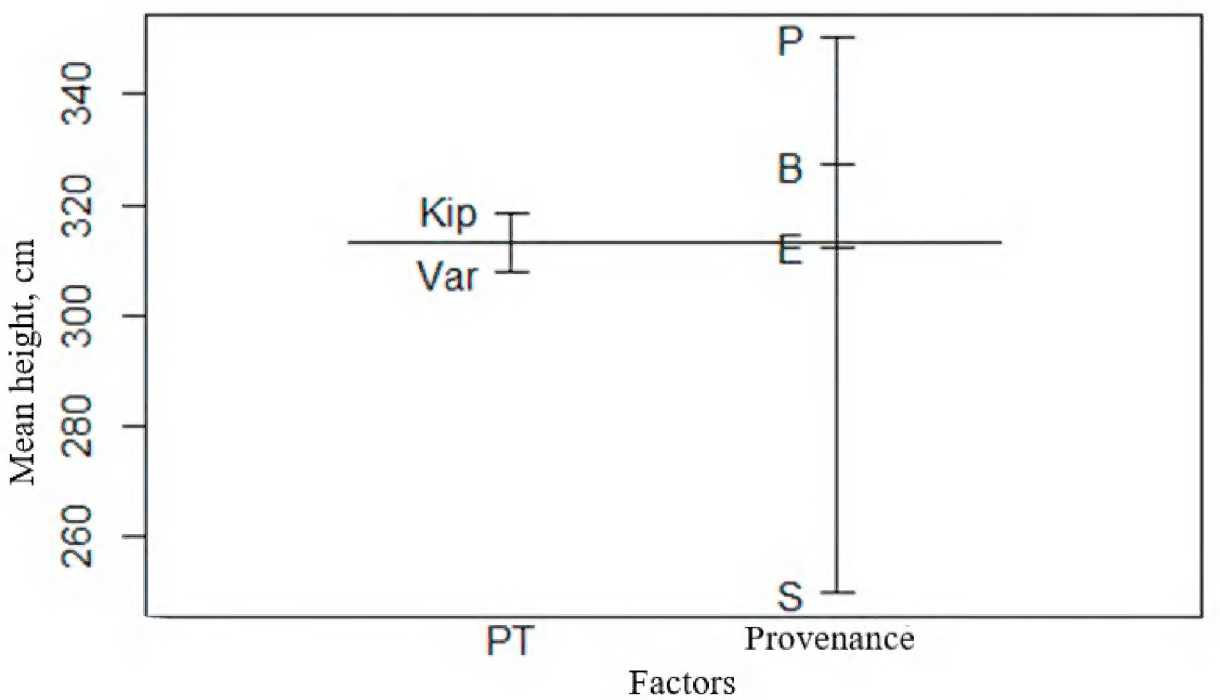

Fig. 3. Mean heights by provenance (S – Silberbach, E – Ebersdorf, B – Berkovitza, P – Petrohan) and provenance trial (PT; Var – Varbitza and Kip – Kipilovo)

Table 3. Results of an ANOVA of heights of 4 provenances at 2 provenance tests (PT)

	DF	Sum Sq.	Mean Sq,	F	*p*
PT	1	20984	20984	1.537	0.215 ns
Provenance	3	810381	270127	19.786	$2.63e^{-12}$ ***
PT x Provenance	3	45999	15333	1.123	0.339 ns
Residuals	680	9283636	13652		

Note: Significance: *** - $p < 0.001$; ns - not significant.

from the height of provenances Ebersdorf and Petrohan, but it exceeds statistically significantly provenance Silberbach. All other comparisons between provenances were statistically significant.

The Bulgarian provenances Petrohan and Berkovitza had better height growth on the 12th as well as on the 8th year after afforestation (Petkova, 2019). One of the reasons was that they originate from the south-eastern part of the beech's natural range and have an earlier development (Petkova et al., 2017). This conclusion is consistent with the studies of other authors (Muhs, 1985; Madsen, 1995; von Wuehlish et al., 1995; Stener, 2002; Matyas et al., 2010), who found that provenances from the eastern and south-eastern parts of the beech range had earlier leaf flushing than those from the western and northern parts. On the other hand, Bulgarian provenances were located in the southern part of the common beech range, and according to Larsen (1985), confirmed by Ballian and Zukić (2011), common beech provenances from the southern part of the range grow faster than those from Northern Europe (Switzerland, Germany, etc.).

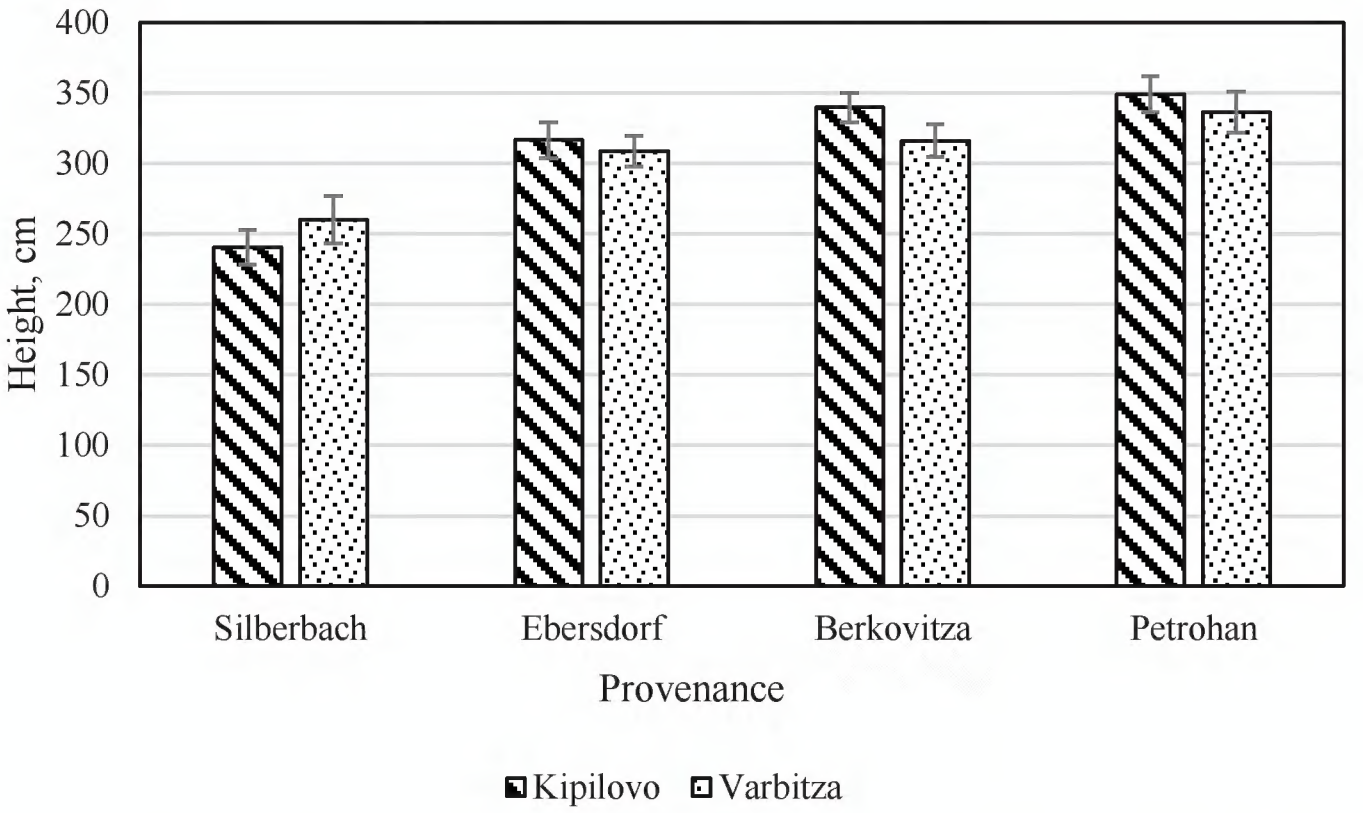

Fig. 4. Mean height of the common beech provenances in the provenance tests in Varbitza and Kipilovo in the 12th year after the establishment

Table. 4. Comparing the differences between the mean heights of the provenances in the two provenance tests by Tukey's method

No	Term	Group 1	Group 2	Null. value	Estimate	Conf. low	Conf. high	p.adj	padj.sig
1	Provenance	B	E	0	-14.7	-45.2	15.8	0.601	ns
2	Provenance	B	P	0	23.2	-8.8	55.2	0.245	ns
3	Provenance	B	S	0	-77.7	-112.0	-43.9	2.88E-08	****
4	Provenance	E	P	0	37.9	6.1	69.7	0.0121	*
5	Provenance	E	S	0	-63.0	-96.7	-29.4	0.0000103	****
6	Provenance	P	S	0	-101.0	-136.0	-65.9	0	****

Note: Significance: **** $p < 0.000$; * $p < 0.05$; ns - not significant

According to Hoffmann (1961), the achieved heights at an early age may not be the measure by which one could accurately determine the growth of particular provenances, or evaluate which provenance has the fastest development, because often there is a change in the growth rate at the late age. Other authors (Vidaković and Krstinić, 1985) consider that more reliable conclusions about the speed of growth in beech provenances can be obtained at the age of 40 years, i.e. for one third of the rotation.

Root collar diameter (RCD)

According to the mean root collar diameter, differences were observed both between the two provenance tests and between the provenances (Fig. 5). In contrast to the

height of the seedlings, higher root collar diameter characterized the provenance test in Varbitza, and the difference was of high statistical significance (Table 5). The arrangement of provenances by mean diameter was slightly different compared to their arrangement by height. With the largest mean root collar diameter in both provenance tests, the provenance Petrohan was distinguished, followed by the Ebersdorf provenance. In the third place was provenance Berkovitza. Provenance Silberbach had the smallest root collar diameter in both provenance tests (Fig. 5). The factor provenance also had a statistically significant effect on the root collar diameter. No statistically significant interaction was found between the two factors – provenance test and provenance (Table 5).

The mean diameter of provenances in the two provenance tests was presented in Fig. 6. In Varbitza it was 67.7 mm and was relatively larger than that in Kipilovo (58.5 mm) as could be seen from Fig. 5. With the largest mean diameter was the Bulgarian provenance Petrohan (75 mm in Varbitza and 65 mm in Kipilovo, and the smallest – the German provenance Silberbach (60 mm in Varbitza and 47 mm in Kipilovo). In second place in Varbitza with approximately the same mean diameter were provenances Ebersdorf and Berkovitza, and in Kipilovo - provenance Ebersdorf. The high level of significance of provenance indicated in Table 5 allows applying Tukey's multiple comparison method.

From the comparison of the mean diameters in pairs (Table 6), it was striking that only the provenance Silberbach significantly differs from the others in terms of this

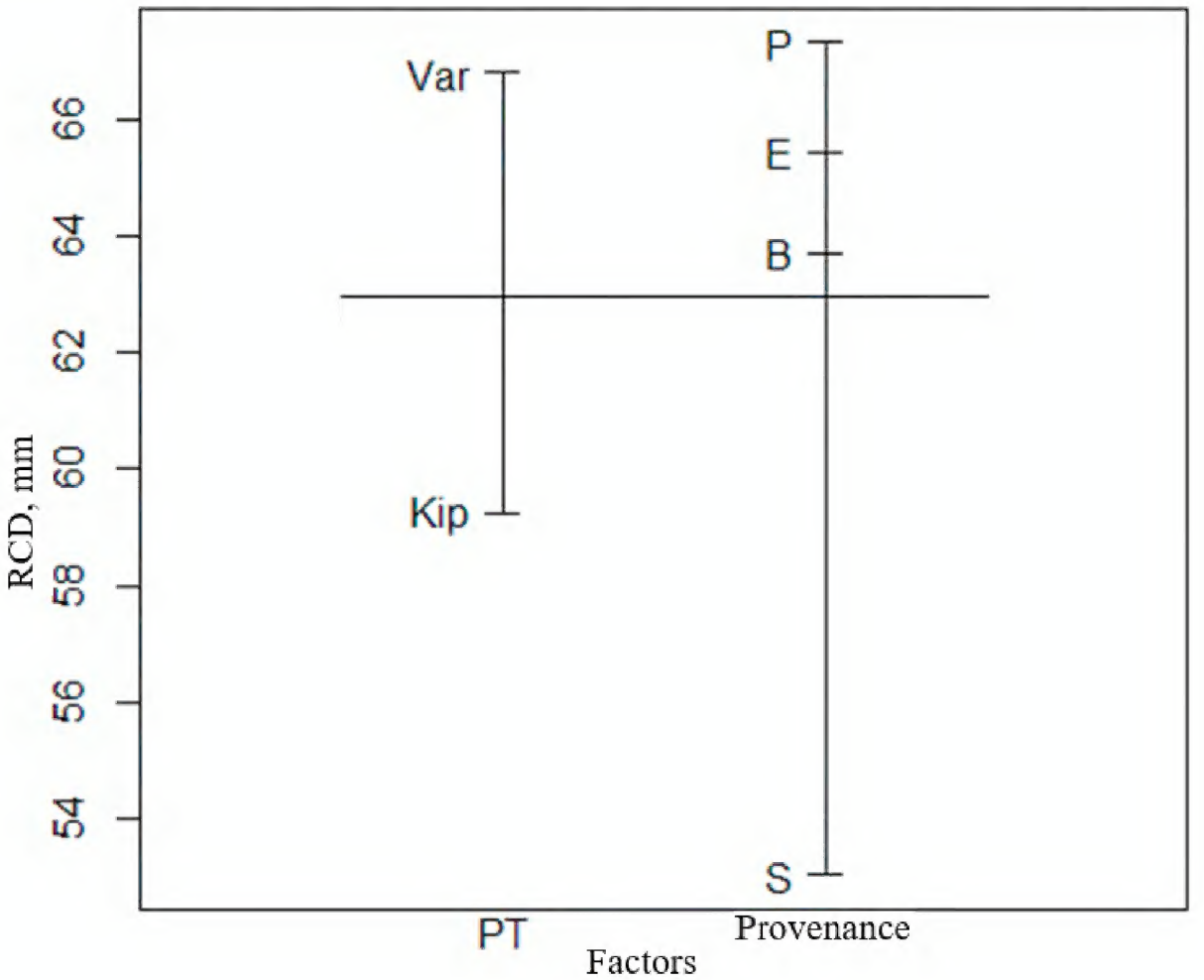

Fig. 5. Mean root collar diameter (RCD) by provenance (S – Silberbach, E – Ebersdorf, B – Berkovitza, P – Petrohan) and provenance trial (PT; Var – Varbitza and Kip – Kipilovo)

Table 5. Results of an ANOVA of root collar diameter (RCD) of 4 provenances at 2 provenance tests (PT)

	DF	Sum Sq.	Mean Sq,	F	*p*
PT	1	9838	9838	16.289	$6.05e^{-05}$ ***
Provenance	3	17624	5875	9.727	$2.73e^{-06}$ ***
PT x Provenance	3	1693	564	0.934	0.424 ns
Residuals	680	410699	604		

Note: Significance: *** - $p < 0.001$; ns - not significant.

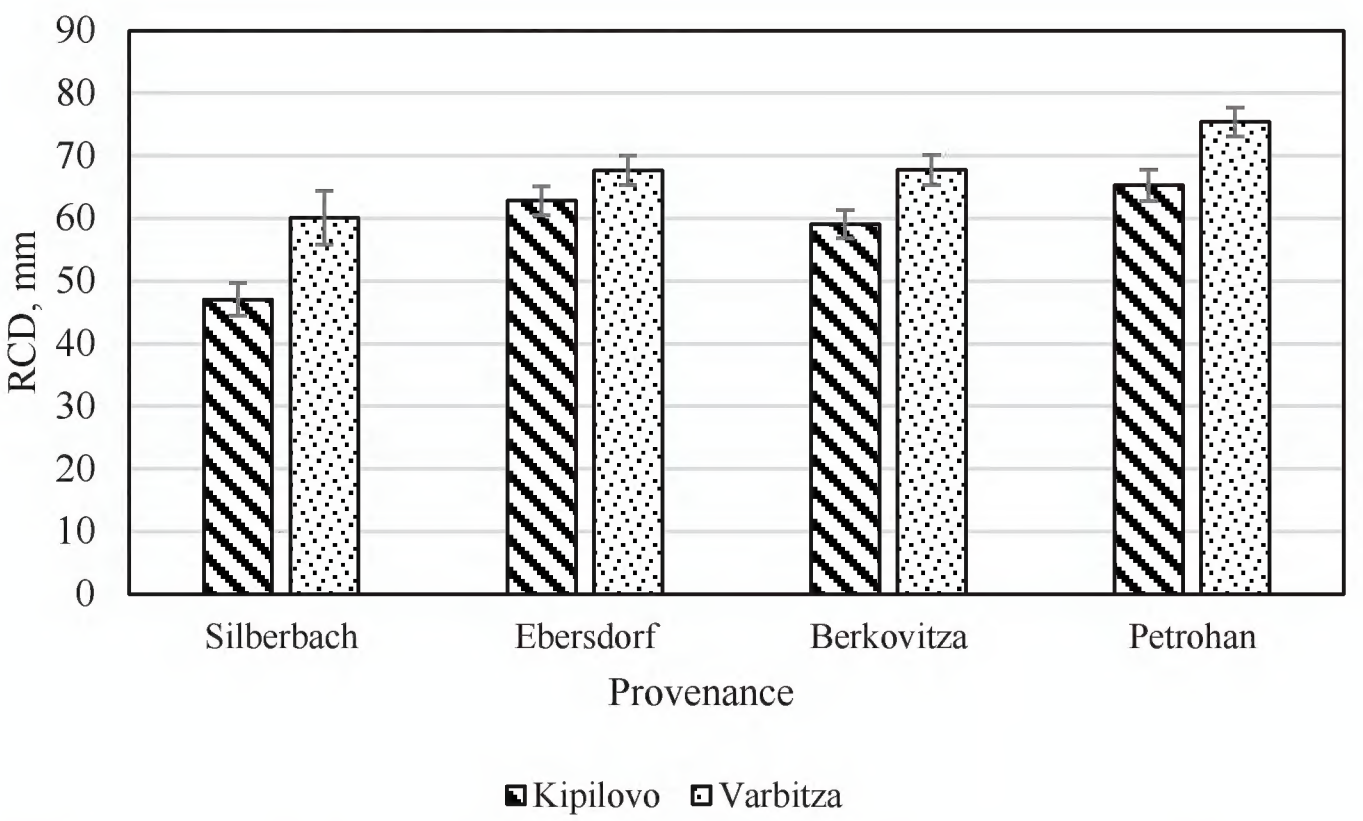

Fig. 6. Mean root collar diameter (RCD) of the common beech provenances in the provenance tests in Varbitza and Kipilovo in the 12th year after the establishment

indicator. The differences between provenances Ebersdorf, Berkovitza and Petrohan were not statistically significant.

The diameter of the seedlings depends not only on the provenance but also on the growth space that is provided when the seedling dyed, because the provenance tests were established under the same scheme. This is probably the reason why the German provenance Ebersdorf was equaled with the Bulgarian one Berkovitza in the provenance test in Varbitza, and in Kipilovo it was displaced.

Provenance Petrohan originated from a place with the largest annual rainfall amount of the four provenances and performs with the best growth and survival in both provenance tests, which were established in places with a relatively drier climate especially in Varbitza. The conclusion of Stojnic et al. (2013), that common beech provenances from wetter locations also perform well in drier continental climate, was confirmed.

Table 6. Comparing the differences between the mean diameters of provenances in the two provenances tests by Tukey's method

No	Term	Group 1	Group 2	Null. value	Estimate	Conf. low	Conf. high	p.adj	padj.sig
1	Provenance	B	E	0	1.7	-4.77	8.2	0.904	ns
2	Provenance	B	P	0	3.6	-3.2	10.4	0.523	ns
3	Provenance	B	S	0	-10.7	-17.9	-3.5	8.07E-04	***
4	Provenance	E	P	0	1.9	-4.88	8.65	0.89	ns
5	Provenance	E	S	0	-12.4	-19.5	-5.25	0.0000547	****
6	Provenance	P	S	0	-14.3	-21.7	-6.85	0.00000561	****

Note: Significance: **** $p < 0.000$; *** $p < 0.001$; ns - not significant

Conclusions

The average survival rate in the 12th year after the establishment of the provenance tests was bigger in Kipilovo (59%) compared to Varbitza (56.8%), most likely due to more rainfall there. The arrangement of the provenances according to this indicator was different in the two provenance tests. In Varbitza, the provenance Ebersdorf had the highest survival rate, and in Kipilovo - provenance Petrohan.

The Bulgarian provenances Petrohan and Berkovitza were with the best height growth in both provenance tests in the 12th year, and in root collar diameter - provenance Petrohan.

The good performance of the Bulgarian provenances shows that, in the event of faster climate changes, we have local provenances with which to support the adaptation of the common beech. It could be recommended for use in drier and warmer places in Germany provenance Ebersdorf, but more definite conclusions about the studied provenances require a longer period of observation.

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